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Final Report

RADIATIVE TRANSFER IN REALISTIC PLANETARY ATMOSPHERES

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Planetary Programs/SL

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George W. Kattawar

Final Report

This is the Final Report for Grant No. 44-001-117. During the course of this Grant a total of 49 publications appeared in scientific journals from 1973 to 1981. There were also 45 scientific reports issued during the course of this Grant.

A number of different topics were investigated. These included the development of a useful Matrix Operator Theory of Radiative Transfer which made possible the exact model calculations of the radiance as a function of height in planetary atmospheres. The Mie Phase Matrix was calculated for various types of particles and was used to calculate the radiance and polarization in planetary atmospheres. The high dispersion spectroscopic observations of Venus made from 1968 were analyzed.

Curves of growth for Venus were calculated and discussed.

A theory for calculating radiative transfer in spherical shell atmospheres was developed. The zonal winds on Venus were studied. Rayleigh scattering was reexamined.

The range of topics covered during the period of this contract is so wide that it seems impossible to summarize the results here. A complete list of the reports and publications is attached; all of these have been mailed to the required mailing list. Those interested in particular topics can easily look up the appropriate articles.

Report Issued for Grant No. NGR-44-001-117

1. Matrix Operator Theory of Radiative Transfer. I. Rayleigh Scattering. Gilbert N. Plass, George W. Kattawar, and Frances E. Catchings.
2. Matrix Operator Theory of Radiative Transfer. II. Scattering from Maritime Haze. George W. Kattawar, Gilbert N. Plass, and Frances E. Catchings.
3. Degree and Plane of Polarization of Multiple Scattered Light. I. Homogeneous Cloud Layers. George W. Kattawar and Gilbert N. Plass.
4. Degree and Plane of Polarization of Multiple Scattered Light. II. Earth's Atmosphere with Aerosols. Gilbert N. Plass and George W. Kattawar.
5. Interior Radiances in Optically Deep Absorbing Media: I. Exact Solutions for One-Dimensional Model. George W. Kattawar and Gilbert N. Plass.
6. Interior Radiances in Optically Deep Absorbing Media. II. Rayleigh Scattering. Gilbert N. Plass, George W. Kattawar, and Judith Binstock.
7. The Influence of Ozone and Aerosols on the Brightness and Color of the Twilight Zone. Charles N. Adams, Gilbert N. Plass, and George W. Kattawar.
8. Phase Matrix Induced Symmetries for Multiple Scattering Using the Matrix Operator Method. Stephen J. Hitzfelder and George W. Kattawar.
9. Interior Radiances in Optically Deep Absorbing Media. III. Scattering from Haze L. George W. Kattawar and Gilbert N. Plass.
10. High-Dispersion Spectroscopic Observations of Venus During 1968 and

(Reports - Continued)

1969. II. The Carbon-Dioxide Band at 8689Å. R. A. J. Schorn, A. Woszyzk, and L. D. Gray Young.

11. Is the Four-Day "Rotation" of Venus Illusory? Andrew T. Young.

12. Comments on "Venus' Spectroscopic Phase Variation: Implications of the Mariner 10 Photographs." Andrew T. Young.

13. A Three Parameter Analytic Phase Function for Multiple Scattering Calculations. George W. Kattawar.

14. Forbidden Ca II in the Sun Unmasked by Way of Venus. R. A. Schorn, A. T. Young, and E. S. Barker.

15. High Dispersion Observations of Venus During 1972: The CO₂ Band at 7820Å. L. D. Gray Young and A. T. Young.

16. The Clouds of Venus. A. T. Young.

17. Scintillations During Occultations by Planets. I. An Approximate Theory. A. T. Young.

18. Multiple Scattered Radiation Emerging from Continental Haze Layers. 1: Radiance, Polarization, and Neutral Points. G. W. Kattawar, G. N. Plass, S. J. Hitzfelder.

19. Multiple Scattered Radiation Emerging from Continental Haze Layers. 2: Ellipticity and Direction of Polarization. G. N. Plass, G. W. Kattawar, S. J. Hitzfelder.

20. Planetary Isophotes as a Clue to Aerosol Characteristics. G. W. Kattawar, A. T. Young.

21. Scattering in the Atmosphere of Venus. I. Curves of Growth for Isotropic Scattering. L. D. G. Young, G. W. Kattawar.

22. Electromagnetic Scattering from a Spherical Polydispersion of Coated Spheres. G. W. Kattawar, D. Hood.

23. Scattering in the Atmosphere of Venus. II. Effect of Varying the

(Reports - Continued)

Scale Height of the Scattering Particles. G. W. Kattawar, L. D. G. Young.

24. Radiance, Polarization, and Ellipticity of the Radiation in the Earth's Atmosphere. S. J. Hitzfelder, G. N. Plass, G. W. Kattawar.

25. Scattering in the Atmosphere of Venus. III. Line Profiles and Phase Curves for Rayleigh Scattering. L. D. G. Young, G. W. Kattawar.

26. An Improved Venus Cloud Model. A. T. Young.

27. Comments on: "Stellar Refraction: A Tool to Monitor the Height of the Tropopause from Space". A. T. Young.

28. High Dispersion Spectroscopic Observations of Venus near Superior Conjunction. I. The Carbon Dioxide Band at 7820Å. L. D. G. Young, R. A. J. Schorn, A. T. Young.

29. High Dispersion Spectroscopic Observations of Venus near Superior Conjunction. II. The Carbon Dioxide Band at 7883Å. A. T. Young, L. D. G. Young, R. A. J. Schorn.

30. Line Shifts Due to Blending. A. T. Young.

31. Interpretation of High-Resolution Spectra of Mars. IV. New Calculations of the CO Abundance. L. D. G. Young and A. T. Young.

32. Planetary Isophotes as a Clue to Aerosol Characteristics. II. Observations of Venus from Spacecraft. A. T. Young and G. W. Kattawar.

33. Radiative Transfer in Spherical Shell Atmospheres. I. Rayleigh Scattering. C. N. Adams and G. W. Kattawar.

34. Clouds and Their Effects on Spectroscopic Observations. L. D. G. Young and A. T. Young.

35. Radiative Transfer in Spherical Shell Atmospheres. II. Asymmetric Phase Function. G. W. Kattawar and C. N. Adams.

(Reports - Continued)

36. High-Dispersion Spectroscopic Observations of Venus Near Superior Conjunction. III. The Carbon Dioxide Band at 8689Å. R. A. J. Schorn, A. T. Young, L. D. G. Young.
37. Radiative Transfer in Spherical Shell Atmospheres. III. Application to Venus. G. W. Kattawar.
38. Phase Matrix and Cross Section Calculations for Electromagnetic Scattering from Two Identical Particles. G. W. Kattawar and T. J. Humphreys.
39. High Dispersion Spectroscopic Observations of Venus near Superior Conjunction: IV. Results for the Carbon Dioxide Bands in the IV-N Photographic Region. L. D. G. Young, R. A. J. Schorn, and A. T. Young.
40. Errors Incurred in a Plane Wave Type Expansion of a Gaussian Beam. G. W. Kattawar.
41. Electromagnetic Scattering from Two Identical Pseudospheres. G. W. Kattawar and T. J. Humphreys.
42. Comment on "New Determination of Rayleigh Scattering in the Terrestrial Atmosphere. A. T. Young.
43. Inelastic Scattering in Planetary Atmospheres. I. The Ring Effect, Without Aerosols. G. W. Kattawar, A. T. Young, and T. J. Humphreys.
44. On the Rayleigh-Scattering Optical Depth of the Atmosphere. A. T. Young.
45. Rayleigh Scattering. A. T. Young.

Publications Issued under Grant No. NGR-44-001-117

1. Matrix Operator Theory of Radiative Transfer. I. Rayleigh Scattering. Gilbert N. Plass, George W. Kattawar, and Frances E. Catchings, *Applied Optics* 12, 314-329 (1973).
2. Matrix Operator Theory of Radiative Transfer. II. Scattering from Maritime Haze. George W. Kattawar, Gilbert N. Plass, and Frances E. Catchings, *Applied Optics* 12, 1071-1084 (1973).
3. Degree and Plane of Polarization of Multiple Scattered Light. I. Homogeneous Cloud Layers. George W. Kattawar and Gilbert N. Plass. *Applied Optics* 11, 2851-2865 (1972).
4. Degree and Plane of Polarization of Multiple Scattered Light. II. Earth's Atmosphere with Aerosols. Gilbert N. Plass and George W. Kattawar. *Applied Optics* 11, 2855-2879 (1972).
5. Theorems on Symmetries and Flux Conservation in Radiative Transfer Using the Matrix Operator Theory. George W. Kattawar, *Journal of Quantitative Spectroscopy and Radiative Transfer* 13, 145-151 (1973).
6. An Explicit Form of the Mie Phase Matrix for Multiple Scattering Calculations in the I, Q, U, and V Representation. George W. Kattawar, Stephen J. Hitzfelder, and Judith Binstock. *Journal of the Atmospheric Sciences* 30, 289-295 (1973).
7. Interior Radiances in Optically Deep Absorbing Media. I. Exact Solutions for One-Dimensional Model. George W. Kattawar and Gilbert N. Plass. *Journal of Quantitative Spectroscopy and Radiative Transfer* 13, 1065-1980 (1973).
8. Interior Radiances in Optically Deep Absorbing Media. II. Rayleigh Scattering. Gilbert N. Plass, George W. Kattawar, and Judith

(Publications - Continued)

Binstock. *Journal of Quantitative Spectroscopy and Radiative Transfer* 13, 1081-1096 (1973).

9. The Influence of Ozone and Aerosols on the Brightness and Color of the Twilight Zone. Charles N. Adams, Gilbert N. Plass, and George W. Kattawar. *Journal of Atmospheric Sciences* 31, 1662-1674 (1974).

10. Interior Radiances in Optically Deep Absorbing Media. III. Scattering from Haze L. George W. Kattawar and Gilbert N. Plass. *Journal of Quantitative Spectroscopy and Radiative Transfer* 15, 61-85 (1975).

11. Solutions of the Equation of Transfer for a Medium Bounded by a Perfect Specular Reflector in Terms of Those for a Perfect Absorber. George W. Kattawar, *Journal of Quantitative Spectroscopy and Radiative Transfer* 14, 157-158 (1974).

12. High-Dispersion Spectroscopic Observations of Venus During 1968 and 1969. II. The Carbon-Dioxide Band at 8689 \AA . R. A. J. Schorn, A. Woszczyk, L. D. Gray Young. *Icarus* 25, 64-88 (1975).

13. Is the Four-Day "Rotation" of Venus Illusory? Andrew T. Young. *Icarus* 24, 1-10 (1975).

14. Forbidden Ca II in the Sun Unmasked by Way of Venus. R. A. J. Schorn, A. T. Young, E. S. Barker. *Solar Physics* 43, 9-14 (1975).

15. A Three Parameter Analytic Phase Function for Multiple Scattering Calculations. George W. Kattawar. *Journal of Quantitative Spectroscopy and Radiative Transfer* 15, 839 (1975).

16. High Dispersion Observations of Venus During 1972: The CO₂ Band at 7820 \AA . L. D. G. Young, A. T. Young, A. Woszczyk. *Icarus* 25, 239-267 (1975).

(Publications - Continued)

17. The Clouds of Venus. A. T. Young. *Journal of Atmospheric Sciences* 32, 1125-1132 (1975).
18. Scintillations During Occultations by Planets. I. An Approximate Theory. A. T. Young. *Icarus* 27, 335-357 (1976).
19. Multiple Scattered Radiation Emerging from Continental Haze Layers. 1: Radiance, Polarization, and Neutral Points. G. W. Kattawar, G. N. Plass, S. J. Hitzfelder. *Applied Optics* 15, 632-647 (1976).
20. Multiple Scattered Radiation Emerging from Continental Haze Layers. 2: Ellipticity and Direction of Polarization. G. N. Plass, G. W. Kattawar, S. J. Hitzfelder. *Applied Optics* 15, 1003-1011 (1976).
21. Scattering in the Atmosphere of Venus. I. Curves of Growth for Isotropic Scattering. L. D. G. Young, G. W. Kattawar. *Icarus* 29, 483-491 (1976).
22. Planetary Isophotes as a Clue to Aerosol Characteristics. G. W. Kattawar, A. T. Young. *Icarus* 30, 367-376 (1977).
23. Electromagnetic Scattering from a Spherical Polydispersion of Coated Spheres. G. W. Kattawar, D. Hood. *Applied Optics* 15, 1996-1999 (1976).
24. Scattering in the Atmosphere of Venus. II. Effect of Varying the Scale Height of the Scattering Particles. G. W. Kattawar, L. D. G. Young. *Icarus* 30, 179-185 (1977).
25. Radiance, Polarization, and Ellipticity of the Radiation in the Earth's Atmosphere. S. J. Hitzfelder, G. N. Plass, G. W. Kattawar. *Applied Optics* 15, 2489-2500 (1976).
26. Scattering in the Atmosphere of Venus. III. Line Profiles and Phase Curves for Rayleigh Scattering. L. D. G. Young, G. W. Kattawar.

(Publications - Continued)

Icarus 30, 360-366 (1977).

27. An Improved Venus Cloud Model. A. T. Young. Icarus 32, 1-26 (1977).

28. Comments on: "Stellar Refraction: A Tool to Monitor the Height of the Tropopause from Space". A. T. Young. Journal of Applied Meteorology 15, 802-803 (1976).

29. A Scenario on Polarization in a Planetary Atmosphere. G. W. Kattawar. Polarized Light - Instruments, Devices, Applications 88, 67-74 (1976).

30. High Dispersion Spectroscopic Observations of Venus near Superior Conjunction. I. The Carbon Dioxide Band at 7820Å. L. D. G. Young, R. A. J. Schorn, A. T. Young. Icarus 30, 559-565 (1977).

31. High Dispersion Spectroscopic Observations of Venus near Superior Conjunction. II. The Carbon Dioxide Band at 7883Å. A. T. Young, L. D. G. Young, R. A. J. Schorn. Icarus (Submitted for publication).

32. Line Shifts due to Blending. A. T. Young. Journal of the Optical Society of America 68, 246-250 (1978).

33. Interpretation of High-Resolution Spectra of Mars. IV. New Calculations of the CO Abundance. L. D. G. Young, A. T. Young. Icarus 30, 75-79 (1977).

34. Planetary Isophotes as a Clue to Aerosol Characteristics. II. Observations of Venus from Spacecraft. A. T. Young and G. W. Kattawar. Journal of Atmospheric Sciences 35, 323-336 (1978).

35. Radiative Transfer in Spherical Shell Atmospheres. I. Rayleigh Scattering. C. N. Adams and G. W. Kattawar. Icarus 35, 139-151 (1978).

(Publications - Continued)

36. Clouds and their Effect on Spectroscopic Observations. L. D. G. Young and A. T. Young. *Proceedings of Symposium on Planetary Atmospheres*, A. V. Jones, Ed., (The Royal Society of Canada, 1977), pp. 51-53.
37. Radiative Transfer in Spherical Shell Atmospheres. II. Asymmetric Phase Function. G. W. Kattawar and C. N. Adams. *Icarus* 35, 436-449 (1978).
38. High-Dispersion Spectroscopic Observations of Venus Near Superior Conjunction. III. The Carbon Dioxide Band at 8689Å. R. A. J. Schorn, A. T. Young, L. D. G. Young. *Icarus* 38, 420-434 (1979).
39. Vertical Extend of Zonal Winds on Venus. D. Crisp and A. T. Young. *Icarus* 35, 182-188 (1978).
40. Radiative Transfer in Spherical Shell Atmospheres III. Application to Venus. G. W. Kattawar. *Icarus* 40, 60-66 (1979).
41. Spectroscopic Observations of Winds on Venus: I. Technique and Data Reduction. A. T. Young, R. A. Schorn, L. D. G. Young, D. Crisp. *Icarus* 38, 435-450 (1979).
42. High Dispersion Spectroscopic Observations of Venus near Superior Conjunction: IV. Results for the Carbon Dioxide Bands in the IV-N Photographic Region. L. D. G. Young, R. A. J. Schorn, and A. T. Young. *Icarus* 41, 309-311 (1980).
43. Errors Incurred in a Plane Wave Type Expansion of a Gaussian Beam. G. W. Kattawar. *Applied Optics* 19, 194-195 (1980).
44. Electromagnetic Scattering from Two Identical Pseudospheres. G. W. Kattawar and T. J. Humphreys. *Proceedings of the Workshop on Scattering by Irregularly Shaped Particles*, D. W. Schuerman, Editor.

(Publications - Continued)

Plenum Publishing Corporation, 1980.

45. Hypersensitizing Kodal Plate, Type IV-N; Ammonia Vs. Silver Nitrate Solution. A. T. Young and D. Crisp. AAS Photo-Bulletin No. 22, 3-7 (1979).

46. Inelastic Scattering in Planetary Atmospheres. I. The Ring Effect, Without Aerosols. G. W. Kattawar, A. T. Young, and T. J. Humphreys. *Astrophysical Journal* 243, 1049-1057 (1981).

47. On the Rayleigh-Scattering Optical Depth of the Atmosphere. A. T. Young. *Journal of Applied Meteorology* 20, 328-330 (1981).

48. Revised Depolarization Corrections for Atmospheric Extinction. A. T. Young. *Applied Optics* 19, 3427-3428 (1980).

49. Rayleigh Scattering. A. T. Young. *Applied Optics* 20, 533-535 (1981).